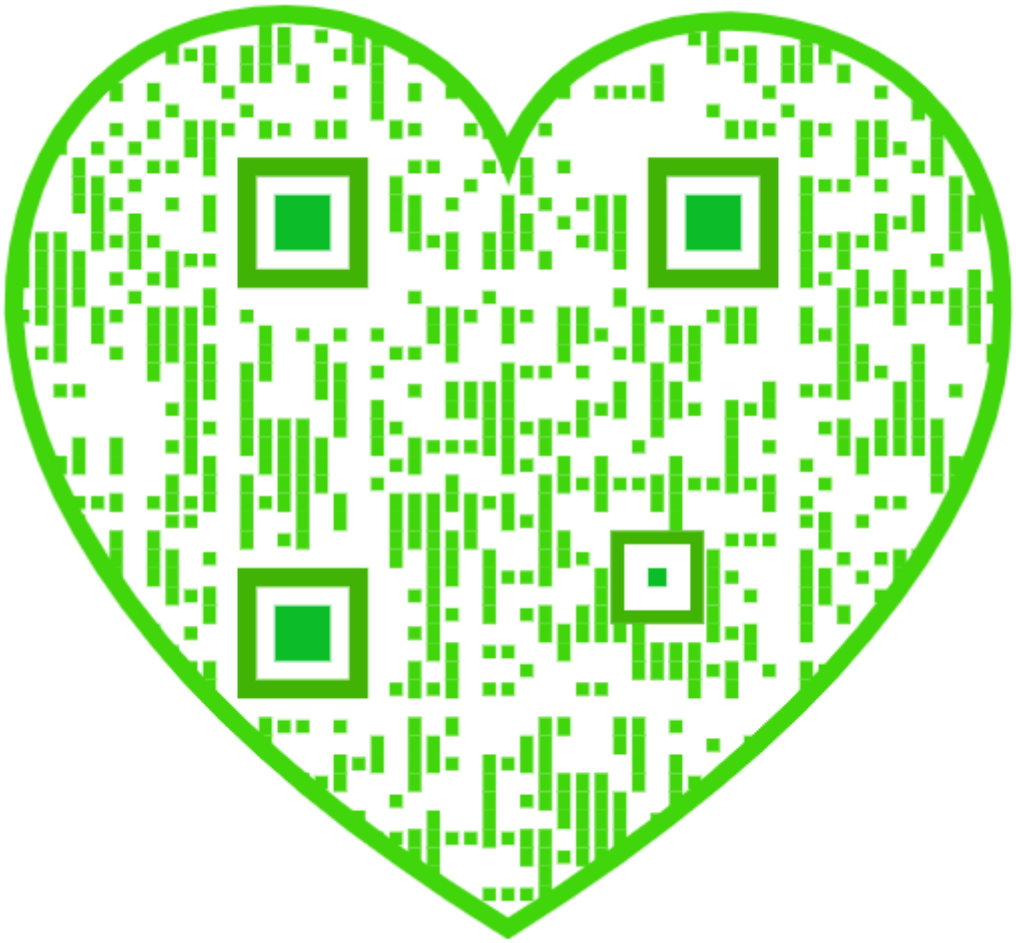

X-RAY APPARATUS AND ITS MANIPULATION.

APPARATUS.

1. **The Production and Definition of X-Rays.**—If a stiff piece of cardboard, coated on one side with a fluorescent salt or chemical, such as calcium tungstate, be held as a screen before the eyes, facing the salt side, and subjected or brought close to a properly constructed and highly exhausted glass tube through which an electrical discharge is passed, the screen will light up or be seen to glow as long as the discharge lasts.

   If, now, a dense body, such as a coin or key, be placed upon the uncoated side of the screen, facing the tube, the eye will perceive its sharply defined shadow.

   In this way, if a photographic plate is made to replace the screen, the shadow outline will appear when the plate has been developed—*i.e.*, chemically treated as described later.

2. This effect upon the screen and dry plate is not due to ordinary light radiated by the tube, because it takes place even when the tube is perfectly lifeless as regards visible light; if now the tube be boxed in, so that it will be perfectly light-proof—say by $\frac{1}{4}''$ thickness of wood—the action will persist with practically undiminished vigor.

3. The study of shadows thus produced shows that the effect is as of rays, similar to light rays, except that the latter or X-rays do not affect the retina directly, and that they are

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able to penetrate wood and other dense bodies; and that they proceed from a point or surface within the tube, travelling in straight lines in every direction.

4. If a purse containing coins, a wooden box with keys, or the human hand be placed upon the screen facing the tube, there will be a dark shadow of the coins in the lighter shadow of the purse; or a dark shadow of the keys in a lighter shadow of the box; while with the hand a dark shadow of the bones will be seen in a lighter shadow of the fleshy hand.

5. These rays, therefore, penetrate solid bodies, but are absorbed in thus penetrating them—the absorption increasing with the thickness of the material directly as its density or specific gravity; for the same density of material directly as its thickness. This law is not rigidly, but only approximately true; there are some absolute exceptions, as, *e.g.*, the diamond, which, while much denser than glass, is very transparent to X-rays.

6. Shadows of all bodies, therefore, whether homogeneous or non-homogeneous, will, in general, show not only the outline of the body as a whole, but a varying depth of shade over their entire area; increase of thickness or density showing relatively to the rest of the shadow a greater density of shade.

7. *Unlike light rays, these rays cannot be reflected or refracted.*

8. No satisfactory explanation of the anomalous character of the X-rays has yet been offered, although much study has been devoted to the subject. For this reason their designation as "X-rays"—a name first proposed by Prof. Röntgen—has been commonly accepted. The significance of the title is derived from the use of the letter X in algebra as representing an "unknown quantity."

GENERATING APPARATUS.

9. We have seen that X-rays are emitted from highly exhausted glass tubes through which electrical discharges are made to pass. As the electrical resistance of such tubes is always very great, these discharges must be of very high potential or pressure. The electromotive force of batteries or commercial lighting and power circuits is entirely inadequate for such a use and must be multiplied by means of specially arranged apparatus; or the required E. M. F. may be developed directly, as by some form of the so-called static machine.

10. In practice the two methods just indicated are the only two known which are capable of producing X-rays in profusion. More exactly, we have:—

X-Ray Generating Apparatus.

A. Transformer Apparatus. { 1. The Induction Coil. 2. The Tesla Coil.

B. The Static Machine.

THE INDUCTION COIL.

11. The induction coil is illustrated diagrammatically in Fig. 1; the various letters have the significance given below. The dimensions, size of wire, etc., are such as would ordinarily be used in the average 10″ coil—10″ referring to the length of the spark.

I—A circular bundle of soft iron wires (No. 17 to No. 22 B. & S.) (length 10 to 15 times the diameter) called the **core.**

P—One or two layers of comparatively large wire (No. 10 to No. 14 B. & S.), wound upon the core and insulated from it. Say 360 turns in all. The **primary.**

S′—Large number of turns of fine wire (about No. 34 B. & S.), wound over the primary, but separated from it by a

considerable thickness ($\frac{1}{4}$ to $\frac{1}{2}$ inch) of insulating material. Say 50,000 turns of wire in all. The **secondary.**

B—Joined by wires to primary through the switch R. **Battery.**

R—Permits battery current to be sent through primary in either direction at will. The **switch** or **reversing switch.**

C—A series of tinfoil sheets connected to a common terminal, interleaved with and separated from a similar series of tinfoil sheets by thin sheets of insulation. The **condenser.**

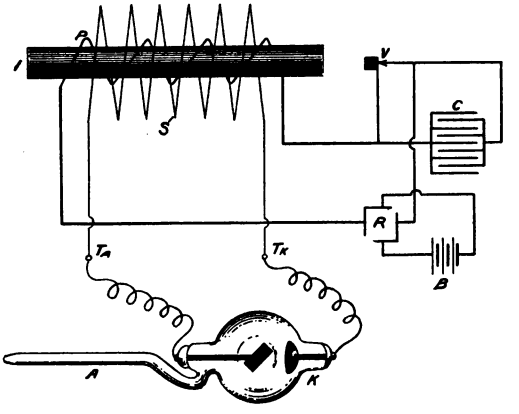

FIG. 1.—CONNECTIONS OF INDUCTION COIL.

V—A soft iron armature carrying a platinum contact point and held away from the core and against a second contact point by a spring. The **vibrator,** or **break,** or **interrupter.**

Ta and Tk are the terminals of the secondary, connected to the tube as shown.

12. The operation of the induction coil is as follows. Switch R being closed, current passes through the primary by way of the vibrator and its two contacts, thus magnetizing the soft iron core, which instantly attracts the armature V. This breaks the primary circuit; the arma-

ture is drawn back by the spring, the circuit again closed, and thus repeating over and over. This part of the action is identical with the operation of the familiar continuously vibrating electric bell. Considering the secondary, we have, at the instant of "make," a momentary induced E. M. F. tending to send a current through it in a direction opposite to that in the primary, and, at the instant of "break," a momentary induced E. M. F. tending to send a current through it in the same direction as that in the primary. In other words, a to and fro current. These induced E. M. F.'s are as many times as great as the E. M. F. of the primary, as the ratio of the number of secondary turns to the number of primary turns.

13. The induction coil is a simple transformer giving regularly recurring and similar cycles. The secondary E. M. F. at "make" is smaller than at "break," owing to the longer time occupied. The terminals of the condenser are connected across the break points of the vibrator. When these points are separated by the attraction of the vibrator, the current charges the condenser; this charge rebounds, as it were, discharging through the primary in the opposite direction. The electromotive force induced in the secondary is, then, the result of a complete stop and sudden reversal of the primary current. Without the condenser, the breaking of the primary circuit is made slower on account of a small arc being drawn at the points of breaking, the current following this arc, so that the rate of change of flux enclosed by the secondary is smaller and consequently the induced secondary E. M. F. is small. A certain definite capacity of the condenser is needed for each different coil, in order to have the best neutralizing effect on the spark. This must be determined by trial, the theoretical calculation being unsatisfactory.

14. The secondary E. M. F. at break is, therefore, very high. At make it will be very much smaller, owing to the con-

siderably longer time required to magnetize the core than to demagnetize it.

15. The effect of this, when the coil is in operation, is to give secondary discharges, in one direction only, at all times when the secondary spark-gap is not greatly shorter than the maximum obtainable length of discharge for that particular condition of running the coil, since the "make" induced current at such times will be of too small

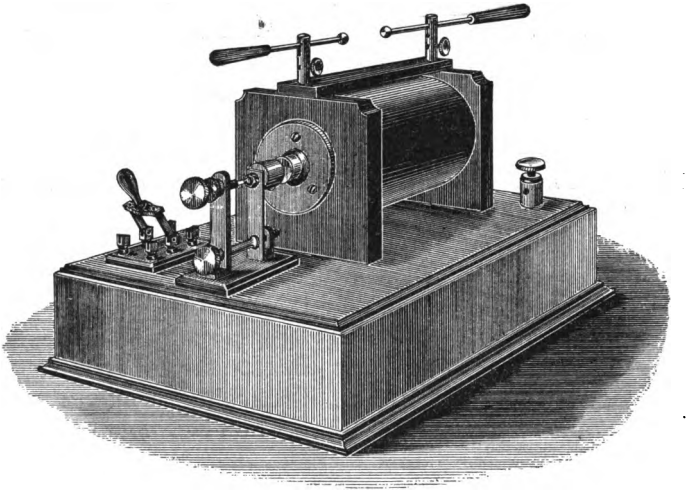

FIG. 2.—INDUCTION COIL.

E. M. F. to get across the gap at all. This is always the condition when X-ray tubes are used.

16. A further function of the condenser is to suppress burning at the "break" terminals, or contact points of interruption, by taking up the energy of the magnetic discharge of the core.

17. Details of Induction Coil.—In Fig. 2 is shown a typical induction coil as made, with trifling modifications of detail, by a number of manufacturers. Fig. 3 is an

outline drawing of the same coil. The principal parts are lettered and described as follows:

S. Secondary coil.

R. Thick hard rubber tube, passing through the secondary, enclosing the primary coil.

P. Primary Coil.

I. W. Bundle of iron wire—the core.

V. The vibrator armature.

C. P. Platinum "Contact Points" of the vibrator.

C. The condenser, usually contained within the base of the apparatus.

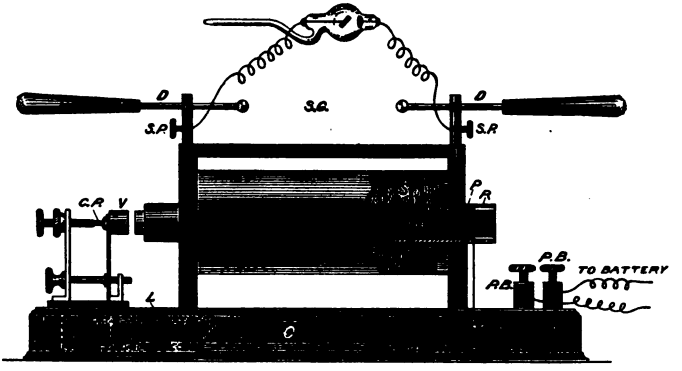

FIG. 3.—PARTS OF INDUCTION COIL.

P. B. Two binding-posts, to which go the ends of the primary. Battery or other source of electrical supply is joined to these two posts and thus becomes part of the primary circuit. They are usually called "Primary Posts."

S. P. Binding-posts forming terminals of the secondary coil, called "Secondary Posts." The Tube is connected to these posts.

D. Adjustable brass rods, with hard rubber handles, called "discharging rods" or "spark-points."

S. G. The space between the tips of discharging rods, called the "spark-gap."

18. **The secondary coil** should be made of high conductivity copper wire, insulated with a single winding of silk and be wound in sections—*i.e.*, flat coils or sections, preferably about $\frac{1}{8}''$ thick. About 50 such sections are required for a 10″ coil. These sections are wound in brass forms, the wire passing through a hot insulating compound as it passes to the form. The latter serves to hold the coil together. When the winding is completed the coils are slipped from the form, which has been made to come apart so as to free the coil. The separate sections are then "stacked" one on top of the other, with discs of paper separating them from each other. Each section is then joined to the next, so as to form a continuous circuit, with the windings all running in the same direction from one end of the "stack" to the other. The whole "stack" is then treated with a bath of insulating compound, the exact method of application varying with different makers. When finally completed, the entire secondary makes a solid cylinder with a hole through its center to receive the rubber tube which encloses the primary. A rubber "jacket" of $\frac{1}{32}''$ sheet is wrapped about it and laced up below.

19. The object of thus winding in sections, and so thoroughly insulating the sections from one another, is to prevent any two adjoining wires from having a very great difference of E. M. F. In a 50 sectioned coil (10″) such as has just been considered, the maximum difference of E. M. F. in any one section is $\frac{1}{50}$ of the whole E. M. F. of the secondary. This $\frac{1}{50}$,—supposing the section to have 1,000 turns,—is practically divided into 1,000 parts, so that any two adjacent turns will only have a difference of potential of $\frac{1}{1000} \times \frac{1}{50}$ or $\frac{1}{50000}$ of the whole. But suppose the secondary is wound to and fro, from one end to the other, as in Fig. 4, and contains the same number of windings or turns deep, viz., 100; we have neighboring turns (taking them vertically along the line of A B), having a difference of E. M. F. vastly greater than in the first case, viz., $\frac{1}{100}$ of the whole. This, as a rule, is too much

for the insulation to stand and the result is a "break-down." Many of the foreign-made and all of the low-priced coils are made in this way; they may present a handsome appearance externally, but are worthless for use.

20. **The primary coil** presents no special feature of interest. It is wound of a greater or smaller number of turns of larger or smaller wire, according to the strength of current or E. M. F. to be used for operating the entire coil.

21. **The core** must be of the softest iron wire obtainable and should be thoroughly annealed, so that its magnetization

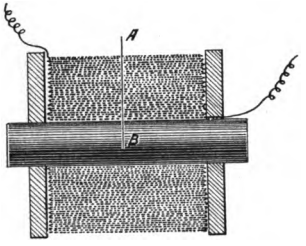

FIG. 4.—SINGLE WINDING.

and demagnetization can take place quickly. Hard iron requires considerable time to magnetize, consequently the induced secondary E. M. F. or current would be considerably decreased.

22. The core should be made of a large number of such wires tied in a bundle, rather than a solid cylinder of such iron. The latter would become the seat of induced currents circulating about its axis, owing to the relatively low resistance it would have there. Going from wire to wire the resistance is high, owing partly to the poor contact, and partly to the natural hard scale of the wire, which is a poor conductor.

23. The chief function of the **discharge-points** and **spark-gap** is that of a safety valve. When the tube is connected (see Fig. 3) the discharge may pass either through

the tube or over the spark-gap. By setting the latter at a given length, therefore, the E. M. F. at the terminals of the tube can never rise higher than the value necessary to burst across the spark-gap. Dangerous strain upon the tube may thus always be avoided.

24. The interrupter, vibrator or break is a most important part of the induction coil. The break must be both sudden and complete, since the induced E. M. F. increases with the *rate* of demagnetization of the core. The frequency of the break, or number of interruptions per unit of time, should also be adjustable, since theory

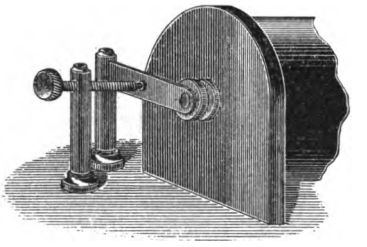

FIG. 5.—VIBRATING BREAK.

shows that there is a certain best rate for a given E. M. F. and current in the primary and a given discharge from the secondary. The contact points must be of platinum, and of sufficient cross-section to avoid heating either by the current or such small sparking as the condenser may not be able to suppress. When large, the points are not liable to be battered out of shape by their continued hammering upon one another. The points should fit squarely upon one another, and open and close without friction.

25. One of the most common forms of breaks is shown in Fig. 5. It has no adjustment for frequency, is usually very badly made, and is in every way most unsuitable for large coils.

26. The vibrator shown in Fig. 6 is very well known and largely used, especially in English-made coils. It gives very fair results on coils up to 8″ and 10″. A is the armature or "hammer-head" to be placed opposite the end of the core; it carries the contact point B, which is held against the point C by the tension of spring D. F tightens D and thus increases the length and vigor of the secondary discharge, since a greater current in primary will be needed to operate the armature.

The actual break in this vibrator is, of necessity, slow, since A is always attracted from a point of rest, and hence requires a very appreciable time to acquire any

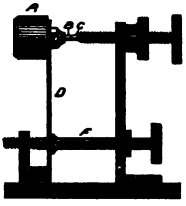

FIG. 6.—VIBRATING BREAK.

great velocity. Furthermore, the violent blow at closure throws spring D into a condition of forced vibration, which entails consequent irregular breaking and corresponding irregular discharge in the secondary.

27. The vibrator in Fig. 7 overcomes the objections just mentioned, and is now used, with but slight modification, by many of the best makers in this country and abroad. The spring G carrying the "hammer-head" is supported below, as in the former case, but is otherwise entirely free. A yoke, H, is rigidly attached to a stiff casting, I, pivoted below and carrying the front contact point, J. The rear contact, K, is controlled by set screws, L. A screw, M, varies the tension of spring Z upon I. In action, the hammer-head is attracted by the core at about the middle of its swing, and when at its maximum velocity strikes the yoke H and breaks the circuit; the

attraction of the "hammer-head" ceases partly by virtue of its spring G, and partly on account of the pull of spring Z. This closes the circuit again, and the core's magnetism immediately begins to act upon the hammer-head, the motion of which, however, it cannot instantly stop, and the head swings on, being gradually brought to rest and its motion reversed, so as to strike the yoke again at high speed.

Frequency in this vibrator is altered by raising or lowering the bob B upon its rod by the aid of a small adjustment screw. That the break takes place with great suddenness in this vibrator is evidenced by the following facts :

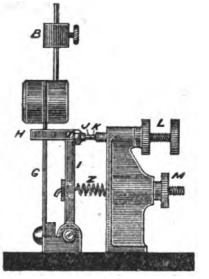

FIG. 7.—VIBRATOR.

1. Arcing at gap is practically *nil* when a proper condenser is used.
2. The rise of temperature at contact points after an hour or two continuous run is inappreciable.
3. Only about half the current required by the form shown in Fig. 6 and similar vibrators is required for this form.

28. The several styles of vibrators just described all operate from the core, which itself is magnetized by the main primary current. The pull on the "hammer-head" varies, therefore, with the primary current, being greater for a large and smaller for a small current, while there is a certain value of current, below which the vibrator will not

operate at all. In the average 10″ coil this value would be that corresponding to a secondary discharge of from about 2″ to 3″.

29. The theoretically correct vibrator should not change in frequency, amplitude or other respect, whether the primary current be large or small. This consideration led to the invention of the vibrator shown in diagram in Fig. 8.

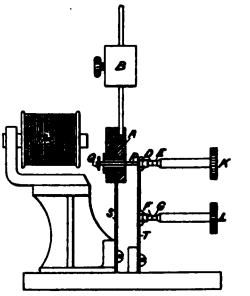

FIG. 8.—VIBRATOR.

The magnet M is energized by its own circuit, which is usually joined to the source of supply in parallel with the primary, a resistance being placed in series or not, as the case may be. This circuit passes through the spring T, contact points F and G, etc. At the top of spring T, but insulated therefrom, is the contact point D, which is extended to the left by a rod P passing through a rubber-bushed opening in the armature A. K is so adjusted that the pin Q is struck by A when the latter is in about the middle of its swing, A continuing its motion until the circuit at M is broken at the points F and G. By varying K the primary circuit may be closed a longer or shorter time as desired, thus allowing a greater or less intensity of core magnetization to be attained with a corresponding secondary discharge. Within reasonable limits, the amplitude of A may also be adjusted by use of the screw L. The period is fixed by position of B, the counterweight or bob.

30. In X-ray work some one or other of the various types of vibrator just mentioned is commonly used. Many other forms of break may be constructed, however, and experts often use breaks of some special make, believing that they so secure better results. Thus, the mercury break is often seen. In this break the contact points are mercury and platinum, the latter being in the form of a plunger or rocker which works in and out of the mercury surface. It is claimed that with this break the actual opening of

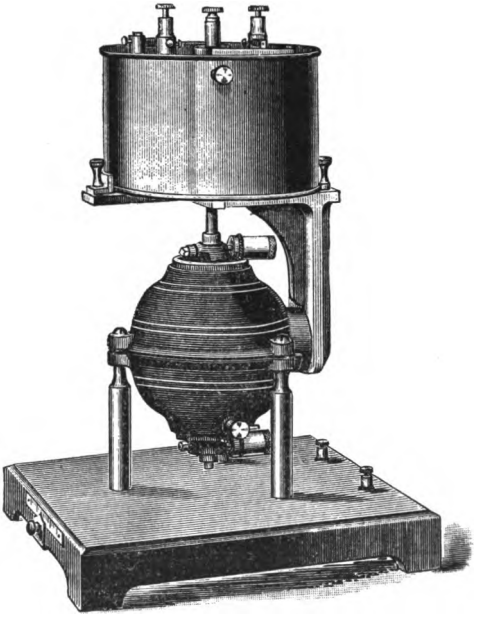

FIG. 9.—ROTARY BREAK.

the circuit is always more sudden than in the platinum breaks, owing to the fact that the mercury always presents a fresh, clean surface. To assist this and prevent oxidation, the mercury cup is usually filled with alcohol or naphtha to cover the mercury surface.

31. Fig. 9 shows a type of break known as the **rotary break.** It is made in different styles by various makers. In the form shown there is a motor with a vertical shaft, the

latter being carried up into a copper can fixed above it. Within the can a brass or phosphor-bronze wheel, with segments of insulating slate let into its periphery, is fixed to the shaft. The primary circuit is carried to this wheel. Against the wheel, and joined to the other terminal of the primary circuit, a copper brush is made to rest. The circuit is thus opened and closed each time a slate segment passes under the brush, brought about by the revolution of the wheel. The can must be filled with distilled water, which prevents burning, at the same time acting as a good insulator. The water must be renewed every hour or so, as otherwise the impurities which soon gather in it cause it to conduct very perfectly, so that the breaks can no longer be obtained.

A small rheostat allows the speed of the motor to be varied at will and thus controls the frequency of the break. A rotary break may have from two to six, or even more breaks per revolution, or, with an average motor speed of 1,200 revolutions per minute, a frequency of from 2,400 to 7,200 per minute or more. With the spring vibrators previously mentioned, 300 to 400 breaks per minute is the maximum, while in larger coils 200 to 250 breaks per minute is the average obtainable number of breaks.

32. The rotary break is, of course, an independent break. It has a much greater frequency variation than any of the spring breaks, and in this respect is superior. The continual attention required in keeping the water renewed and the break-wheel trued up, however, has prevented the extensive use of the apparatus just described.

33. In some forms of rotary breaks the water bath is dispensed with and the break-wheel runs dry in air. The burning of the brushes is so excessive and the noise so disagreeable, however, that it is doubtful if this form of break has ever been a success.

34. The Condenser.—Many condensers are made of paraffined paper and tinfoil simply laid in alternate sheets.

Such condensers usually prevent full spark lengths being attained, owing to their large "absorption" and leakage.

35. Condensers made of paper and tinfoil, in which the former has been subjected to a proper mixture of beeswax and resin to act as the insulating agents, laid between alternately connected sheets of tinfoil, and the whole treated with a hot insulation mixture in vacuo, show but very little absorption, give high insulation and maximum capacity in a given space.

Condensers of mica and tinfoil similarly made are also good, though no better than the vacuum beeswax condenser just described, and are much more costly.

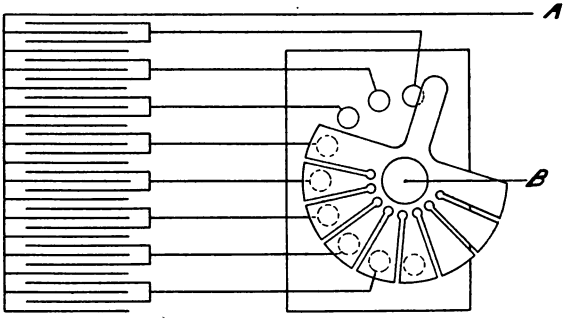

FIG. 10 — ADJUSTABLE CONDENSER.

36. For a coil to give best results the capacity of the condenser must have, very closely, a certain fixed value dependent upon a number of factors: viz., the primary current, frequency of break, length of secondary discharge, etc. As these factors are themselves different at different times, as we do one kind of work or another, to develop large amounts of energy or small, it follows that the condenser can, as a rule, never be more than approximately correct.

37. The adjustable condenser was invented to overcome this defect. Its principle is depicted in Fig. 10, where a special form of switch is shown joined to the condensers.

One set of sheets is connected to the common terminal A, while the other set of sheets is divided into a number of equal groups, each one of which is carried to a pin of the switch. By moving the switch handle, a brass plate, to which it is attached, connects a greater or lesser number of these pins to the terminal B, thus putting a correspondingly greater or lesser number of condenser sections in circuit.

38. Source of Primary Current.—The source of primary current may be either primary battery, storage battery, or from a dynamo or commercial lighting circuit.

39. Primary batteries are somewhat expensive to operate and require considerable attention as regards cleanliness and renewal of chemicals. For these reasons, they should not be used when either of the other two sources is available. If they must be used, probably the Edison-Lalande will prove most satisfactory. Either the Grove or Bunsen may also be used. Gravity batteries or batteries using sulphate of copper, or those using ammonium chloride (sal-ammoniac), are unsuitable, as they can furnish but small currents.

40. The storage battery is very convenient, and is preferably had in the form of a portable battery, *i. e.*, two, three or as many cells as are required, mounted in an oak box with handles for carrying. As such batteries come from the makers, they are usually charged and need only to have the acid added.

41. To charge storage cells a permanent arrangement as given in Fig. 11 may be employed. It can be installed by any electrician, or be home-made for a small cost.

A number of incandescent lamps are connected in parallel or multiple series with the battery. The lamps each offer a known and certain resistance to the current, and the necessary number allow of the proper charge for the storage battery. The exact number of lamps required

depends necessarily upon the size of the battery to be recharged. Larger lamps may be used, in less number accordingly. By referring to the following formula the value of current so obtained is shown:

$$\text{Current (ampères)} = \frac{\text{E. M. F. (volts)}}{\text{R (ohms)}}.$$

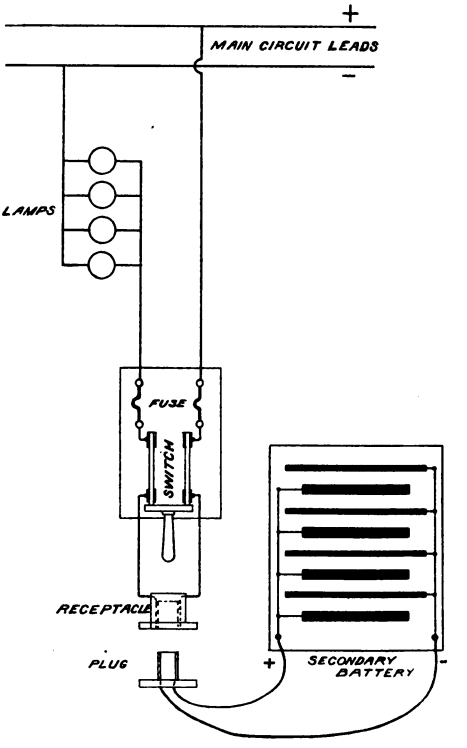

FIG. 11.—CONNECTIONS FOR CHARGING STORAGE CELLS.

The ordinary 16 c. p. 110-volt incandescent lamp has a resistance of 220 ohms. The 32 c. p. lamp has one-half that resistance. For the ordinary 4-cell battery usually employed, two 32 c. p. lamps are necessary for the resistance.

The cell should charge evenly at a rate of, say, 3 ampères

per hour for a cell of 30 ampère-hours capacity. The potential of a single cell, charged, varies from 2.4 to 1.7 volts.

The secondary battery should never be allowed to run as low as the latter voltage and should be recharged when below 1.8 volts.

The length of time necessary to charge a battery depends upon its capacity in ampère-hours. A good way to tell this is to charge the cells until sulphuric acid gas is given off freely through the little holes on top of the battery made for this purpose; or when the cell solution turns to a milky color the recharging should stop.

The solution lost by evaporation should be replaced with the solution of acid already referred to.

42. Use of Lighting Circuit.—Where a direct lighting circuit of not over 110 volts is available, it is to be preferred to either primary or storage batteries. It is always ready and requires no attention beyond the opening and closing of the control switch. The supply of energy available is also practically unlimited, while with batteries there is always a limit to the maximum current which may be obtained. In a battery-coil, the manufacturer always prices the coil with the smallest number of cells which will just decently give the rated spark. This is to keep the price of the outfit down, batteries being expensive. The break frequency will necessarily be slow, since the greater the frequency, the greater will the spark-length be—approximately. With more current the discharge becomes much more vigorous, while with the increase of frequency it becomes much more nearly continuous.

Both these factors mean an increase of energy developed in the tube, and increase of energy there means increase of efficiency. Hence (unless specially arranged for by the manufacturer at a very considerable increase of cost) the battery-coil will invariably be much less efficient than the commercial circuit-coil of the same rated spark-length.

43. When the commercial circuit is used, a rheostat must be placed in series with the primary, to control the current. This rheostat will use up in itself, in the form of heat, a very considerable proportion of the total energy supplied by the circuit. At the best, a 10″ or 12″ coil cannot be made to take more than about 25 volts, leaving the rheostat, on a 110-volt circuit, to take up the remaining 85 volts. To avoid this very considerable waste of power in the rheostat, we may use what is known as a "motor transformer" or "motor generator." This is a small machine having a double armature, one end of which is wound to run as a motor, 110 volts, while the other end has a winding to deliver current at, say, 25 volts. Such a machine, therefore, when connected to the 110-volt mains, will deliver current to the coil at the correct voltage with no waste, except the very small loss of conversion in the machine.

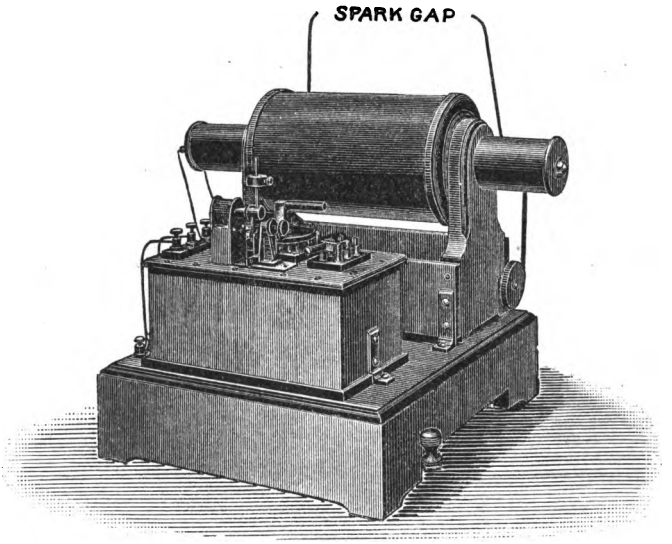

FIG 12. - X-RAY COIL

44. Until the invention of the break typified by Figs. 7 and 8, which may be called the "hammer-head" type, it was impossible to run large coils on commercial circuits of from 50 to 110 volts. The "hammer-head" break, however, is so sudden and so long that the arc has no chance to establish itself across the points, as it did with the older types of coils.

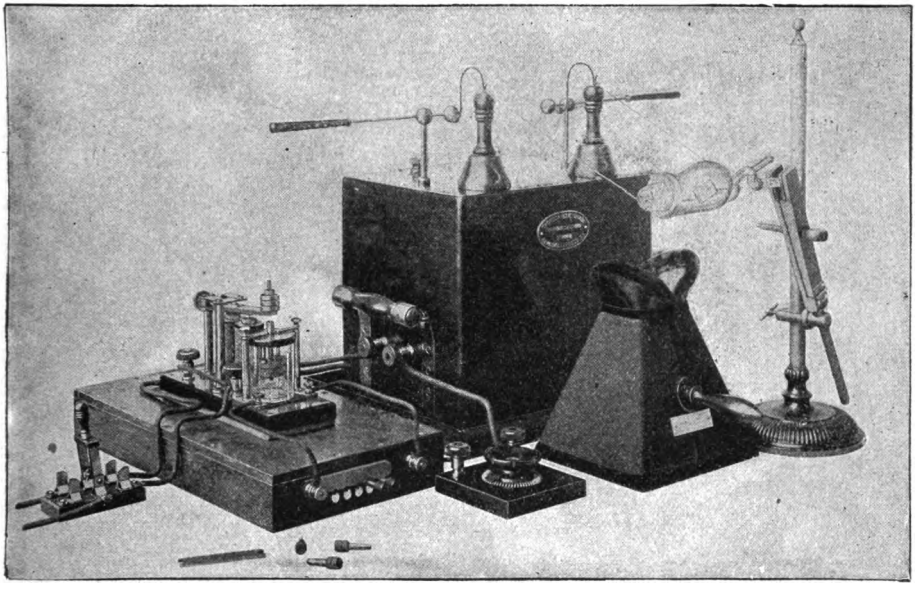

FIG. 13.—X-RAY COIL.

45. X-Ray Coils.—Several X-ray coils, as made by various manufacturers, are shown in Figs. 12, 13 and 14. Commercially they are known as X-ray machines, rather than as induction coils. In Fig. 13 the coil proper is contained in the large box to the right. The box at the left contains the condenser, adjustable by use of the plug and blocks seen at the end; the vibrator is on the condenser box and is a "hammer" break, the vibrating bob or hammer striking downward upon a vertical spindle which separates the contact points under water contained in the

glass cup. Fig. 12 is a high voltage apparatus—*i.e.*, 50 to 110 volts. The rheostat is beneath the base; its handle protrudes below at the right. The condenser is in a separate box, shown in the front of the figure, and upon this same box are mounted the vibrator, condenser switch, main switch, etc. The machine of Fig. 14 is also a high voltage machine.

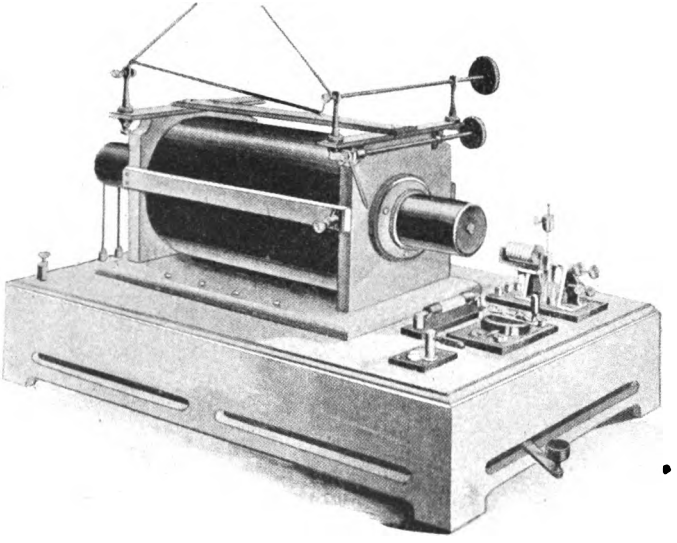

FIG. 14.—X-RAY COIL.

46. Rating and Size of Coils.—Coils are rated according to the maximum length of spark which may be obtained from the secondary, and are spoken of as 4″, 8″, 10″, etc. For X-ray purposes, coils smaller than 4″ need not be considered. From 4″ to and including 15″ practically every inch is represented, though many makers prefer to limit sizes by omitting every other inch, cataloguing thus: 4″, 6″, 8″, 10″, 12″, 15″.

Recently a few coils up to 18′ spark-length have been made, though it is questionable whether such large instruments are necessary, since no tube has thus far been obtained which can utilize more than a small percentage of the energy furnished by such a coil.

THE TESLA COIL.

47. The Tesla coil is shown in diagram in Fig. 15. It consists essentially of two induction coils, the secondary current of the first being used to charge a Leyden jar or condenser. The primary of the second coil is joined in series with the spark-gap G to the two coatings of the Leyden jar. When the latter is fully charged it discharges across the gap G, this discharge being, by well-known laws of electrical circuit flow, an oscillating one of exceedingly high frequency—millions or more per second. The primary of the second coil is thus excited by an alternating current of great voltage and high frequency, so that its

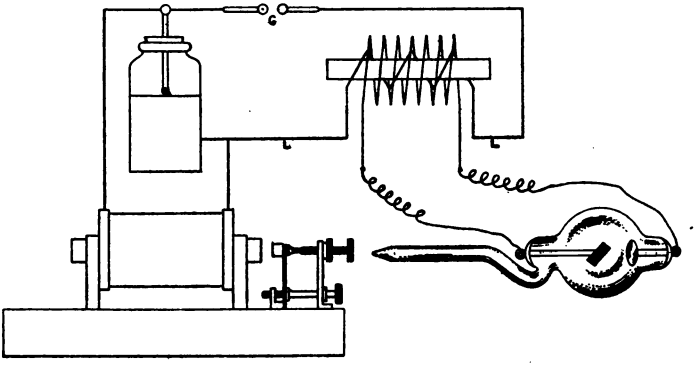

FIG. 15.—TESLA COIL CONNECTIONS.

secondary produces a discharge of still greater E. M. F. of the same high frequency. This final E. M. F. is so great that it is generally necessary to immerse the entire second coil, primary and all, in a tank of oil, since few solid insulations are capable of standing such great E. M. F.'s without break-down.

48. In practice the Leyden jar is replaced by a special condenser made like an induction coil condenser, but with sheets of $\frac{1}{16}''$ to $\frac{1}{8}''$ thick window glass acting as the insulator. Instead of tinfoil, sheets of copper foil are used for the conducting sheet.

49. The induction coil of the diagram is replaced by a small, closed magnetic circuit transformer—*i.e.*, practically an induction coil with an iron ring for a core, instead of a straight bundle of iron wires. A much smaller number of turns is employed in the secondary of this coil than in the ordinary induction coil.

50. The second induction coil or **Tesla coil** proper has usually only a few turns of heavy copper strip for a primary.

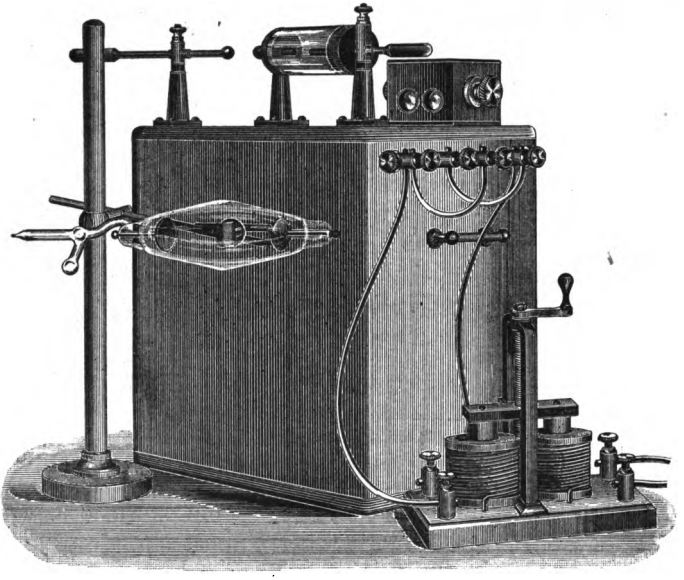

FIG. 16.—TESLA COIL.

This is wound upon a cylinder of glass rods. Upon an outer cylinder of glass rods is wound one layer only of fine wire—say No. 30 to 34 B. & S.

51. The oscillating excitation of the Tesla coil is essential to its efficient operation. This oscillating character hinges upon the air-gap, G, which must not allow the current jumping across it to become continuous. Various devices are therefore employed to "blow out" the spark at this

point immediately it is established. Thus, an air blast operated by a motor or foot bellows may be used. A strong electromagnet, placed with its two poles on opposite sides of the gap, will also do, or a wheel carrying a number of equally spaced radial arms may be used, acting as one terminal of the gap, in such a way that when it is revolved by a motor, these arms successively make and break the spark. "Non-arcing" metal may be used for the spark electrodes; it proves fairly effective without the above-named devices.

In Fig. 16 is shown a commercial Tesla coil. The whole is contained in the large box. Gap G in Fig. 15 is here placed inside of the little top box at the rear right-hand corner of the main case. Adjusting screws permit the gap to be increased or decreased at will, while mica windows in front permit the spark to be seen when adjusting the apparatus. The little containing box is of vulcanized fibre and is used so that the noise, which is of an intensely irritating and rasping character, may be suppressed.

The spark-gap at the left, in front, is the regular parallel gap across the tube terminals—the safety valve. Within the glass tube at the right is a second gap which is in series with the tube, and thus serves to regulate the amount of energy passing through it.

At the right of the apparatus is an "inductance" or choking resistance, by use of which the flow of primary current into the apparatus is adjusted.

THE STATIC MACHINE.

52. By the static machine is meant any form of apparatus which produces a difference of electric potential or E.M.F. by means of friction or the induction of static charges, or both.

The original electrical machine invented by Von Guericke was such a friction apparatus. However, in the modern apparatus made, the principle of continuous induction, as

set forth by Holtz, is followed, giving the most satisfactory results.

53. Figs. 17 and 18 illustrate two of the best known types of the modern induction machine, the former representing a late modification of the Toepler-Holtz Machine, principally used in America and Germany; the latter illustrates the Wimshurst Machine, used extensively in England.

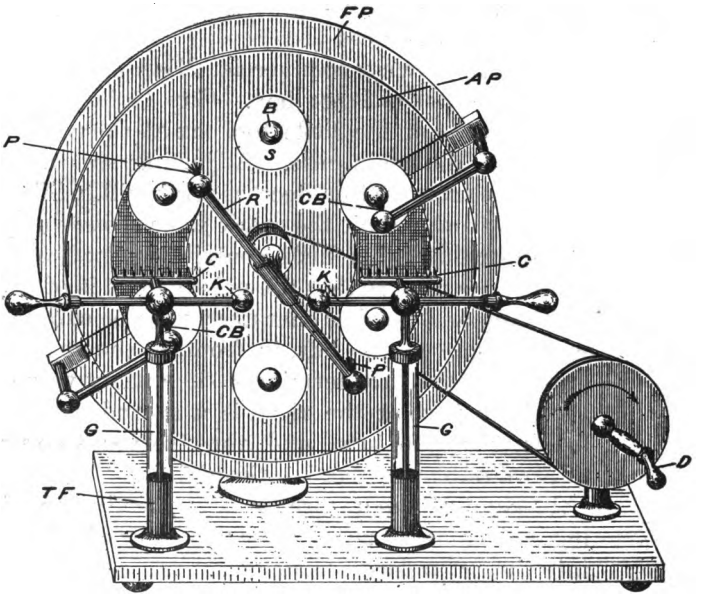

FIG. 17.—TOEPLER-HOLTZ MACHINE.

54. The Toepler-Holtz Machine consists essentially of a modified Holtz apparatus, except that in the former a number of metal discs, termed "carriers," are cemented at equal distances from one another on the front surface of the revolving plate. The revolving plate may be distinguished from the fixed glass plate in back of it by the fact that it is mounted upon a horizontal axis, perpendicular to its center, made to revolve by the aid of a fixed pulley mounted upon its axis and connected by a belt to

a driving wheel, turned by the aid of a crank. The stationary plate is usually placed about ¼ inch from the revolving one, and instead of the discs has two conducting sectors of paper and tinfoil, each lying upon the same circle as the buttons of the front plate and occupying about 90° of an arc at the two extremities of the same diameter. These sectors are connected to several little brushes which pass around and over the front surface of the revolving plate directly over the little brass carriers.

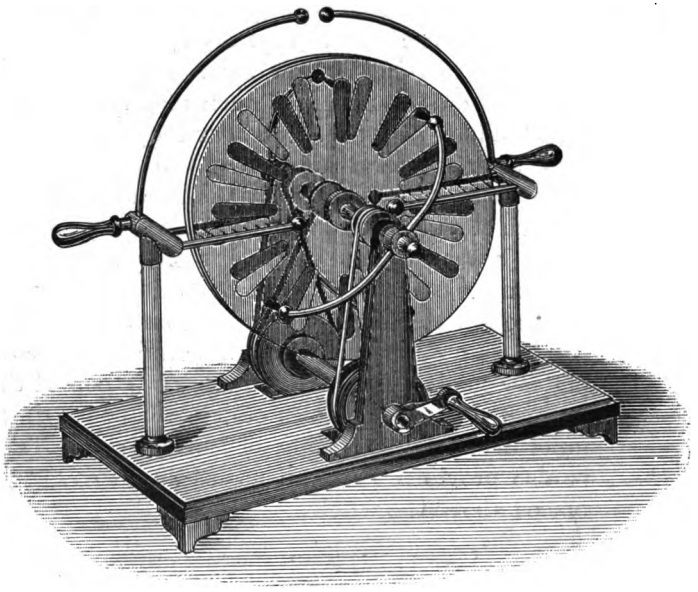

FIG. 18.—WIMSHURST MACHINE.

Two or more insulated metal combs are also placed in front of the discs, coming in contact with them as the plate is made to revolve.

If, now, the plate is revolved, a separation of static potentials is effected, opposite charges going to charge the inner armatures of two Leyden jars, as + and − respectively. When these jars are fully charged, they discharge across the spark-gap formed by two horizontal metal rods placed at the front of the machine.

The spark discharges are heavy and occur at regular intervals, a considerable number per second, if the plate is revolved at its normal speed. A switch is usually provided, by which the Leyden jars may be disconnected, the discharge then passing across the gap without first charging them; in this case the spark discharge is thinner, less noisy and practically continuous.

55. In the **Wimshurst** machine the glass plates are of equal size and so arranged as to revolve in opposite directions. The carrier discs of the apparatus just described are here replaced with long narrow strips of thin metal cemented upon the outer surface of each plate. These sectors or strips radiate outward from near the center and terminate near the peripheral margin of the plate. Small raised metal discs are placed upon the metal sectors in a circle in such a way that when the plates are revolved small metal brushes, mounted on opposite ends of two curved rods, make contact with them, so generating the current of electricity. Insulated brass combs are placed opposite to each other on a line horizontal with the axis of the plates—one pair for each plate. They collect the current generated through fine metal teeth, conveying it to the inner armature or coating of Leyden jars. The machine is also provided with an adjustable spark-gap, usually placed above the whole.

56. Both machines just described—in fact, all static machines —are subject to some disadvantages. These are:

1st. They can give satisfactory results only when thoroughly dry. This objection has been of late, however, greatly overcome. 2d. It is impossible to foretell which side or conductor is + and which —, as the direction of the current delivered by the apparatus is entirely an accidental action or idiosyncrasy of the machine.

57. To ensure dryness and the ability to work the machine at all times, whether in dry or moist atmosphere, it may be enclosed in an air-tight case, made preferably of

glass. The apparatuses now made are so constructed that their movable parts rotate upon ball-bearings to overcome friction and loss of power. Again, calcium chloride or phosphorus pentoxide may be placed within the machine, in small cups, to keep the air within the case continually dry.

58. To overcome the disadvantage of the change of polarity, the connections leading from the discharge gap or prime conductors to the tube must be so arranged as to permit of ready reversal.

Means to accomplish this have been generally provided for by the manufacturers of X-ray static machines.

59. **The discharge of the static machine** has been described as a series of intermittent impulses due to the fact that a sufficient length of time must elapse after each individual discharge of the Leyden jar for the latter again to become charged.

While the E. M. F. of these discharges is high, the quantity of electricity generated, or passing, at each discharge is quite small, that is, the amount of energy developed is small.

60. Therefore, for satisfactory X-ray work, where considerable energy is required, a large machine having more than two plates is necessary. The six- and eight-plate machines wherein the plates are connected in parallel are perhaps the most desirable. The quantity of electricity developed by such an apparatus is sufficient to charge any vacuum tube, giving very satisfactory results.

Tubes used with the static machine should be of larger size than those used with the coil, as they seem to give the best results.

The heating of electrodes is not so marked in using this machine, and piercing is rarely, if ever, experienced.

The principal advantages the static machine has over the induction coil are the following:

A. It is always ready for use, as no battery of cells, that get out of order frequently, is needed.

B. Tubes used with the static machine have longer life than those used with the coil.

C. It is readily manipulated, without danger of burning or shocking.

D. It can be utilized for therapeutic use, which the coil cannot be under any circumstances.

TUBES.

61. Imagine a cylindrical glass tube, say 4″ long and 1″ in diameter, with wall-thickness of about $\frac{1}{16}$″. In each end of this tube, which must be closed, is sealed a platinum wire

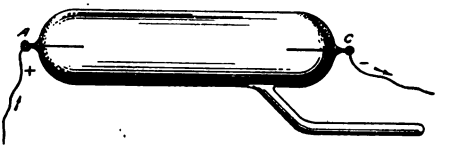

FIG. 19.—GEISSLER TUBE.

projecting a short distance within the tube, and formed into hooks without for connection to the terminals of an induction coil or other generating apparatus. Near one end is a smaller "sealing-off" tube, which serves originally (before its end is closed) for attachment to an air-pump, and later as a handle or support. Such a tube may be considered as a typical or fundamental idea from which to study X-ray tubes. (See Fig. 19.)

62. If such a tube be connected to an active coil, whose spark length is less than the distance between inside ends of the two platinum wires or "electrodes," before exhaustion no change in the spark discharge will be noticed between the terminals A and C. After a few strokes of the pump, however, the tube begins to fill with rosy light, showing

first at the electrodes and gradually extending as exhaustion continues, until the entire body of the tube is filled. Sometimes the color has a greenish tinge, sometimes white. If the exhaustion is continued the body of color breaks up into rings of color more or less sharply separated from one another, continually shifting their position in the tube with a sort of tremor-like motion. In this condition the tube is said to be striated, the rings being called *striæ*.

63. These light-effects vary in color and form with the exact shape of the tube, the character of the glass, the degree of vacuum, the temperature, etc. The general character

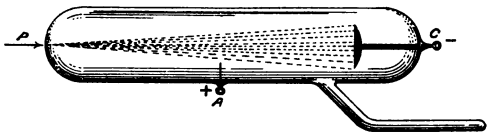

FIG. 20.—CROOKES TUBE.

of the effect remains, however, much the same, and the tube is known generally as a **Geissler tube.** The degree of exhaustion necessary to produce these Geissler effects never exceeds 1 or 2 mms. of mercury.

64. If, now, the exhaustion be carried still further, for which mercury pumps of the Sprengel form must be employed, the character of spark discharge alters completely. The milky colors disappear and are replaced by a general green glow upon the inner surface of the tube. This glow is usually much more conspicuous near one end of the tube than at the other.

65. If, now, we shape the tube as in Fig. 20, replacing one wire by a concave disc, C, whose center lies opposite to P, and place the other electrode, A, on the side, and subject the exhausted tube to an active spark discharge, we shall see upon the surface P a small point or disc of intensely green light. After a few moments this glass surface will

become very warm, and may finally even melt if the tube is run too long. Careful inspection shows that this light spot is the apex of a beam which passes through the tube from C to P.

66. The electrode, C, from which the beam appears to start, is known as the **kathode,** *and is always negative.* The other electrode, A, is called the **anode,** and is *positive.*

67. The rays of the kathode stream are always perpendicular to the kathode surface. If the kathode is a flat circular disc the kathode beam will be a cylinder of uniform cross-section. If the kathode is of very short radius the cone of kathode rays is of small height.

68. When these kathode phenomena occur, the vacuum is said to be a *Crookes vacuum,* and the tubes *Crookes tubes.* These vacua are very much higher than the Geissler vacua, and are, at best, not over a few millionths of an atmosphere.

69. Just what takes place in the Crookes tube is not exactly known. The accepted theory is that known as the "mean free path" theory. This assumes that at normal air pressure the air molecules are so closely crowded that a given molecule cannot travel a distance greater than a few times its own diameter without striking a neighbor. With the high exhaustions, however, the number of molecules becomes so small that a molecule may travel a considerable distance, say $\frac{3}{4}''$ or so, before striking another. The electrification of the kathode is supposed to give direction to these molecules—which are, of course, in continual motion, according to the kinetic theory of gases—by charging them with negative electricity and then hurling them violently away from itself in directions normal to its surface. This theory of the nature of the kathode makes it a stream of electrified particles, and is supported by the fact that two such parallel streams exert a mutual action on each other, and that the beam is deflected by a neighboring magnet, etc.

70. Geissler tubes do not produce X-rays, while Crookes tubes do.

71. **The immediate source** from which the X-rays proceed is the surface upon which the kathode ray impinges. In Fig. 20 the surface P gives off X-rays.

72. More generally, X-rays will be produced at *any* surface within a Crooke's tube upon which a kathode stream is allowed to impinge.

73. **Focus Tube.**—The most efficient type of X-ray tube is a tube in which the kathode stream is focused by a con-

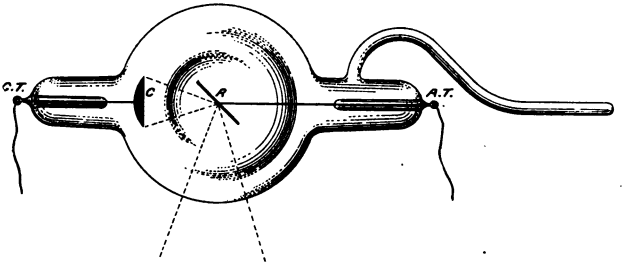

FIG. 21.—FOCUS TUBE.

cave electrode upon a platinum reflector placed within the tube at an angle to the axis of the stream. Such a tube is termed a *focus tube.*

74. A common form of such a tube is shown in Fig. 21. Here the central portion has been expanded into a large spherical bulb. This enables a large cone of X-rays to be used through practically a uniform and small thickness of glass, which is very important, as glass is very opaque to X-rays. A sphere gives maximum strength, of course, for minimum thickness. At the center is the inclined plane or "spade" or "reflector" of platinum upon which the kathode C concentrates its stream. The kathode electrode should be of aluminum, accurately trued and highly polished. It must be carefully set, so that the apex

of the kathode cone is of as small an area as possible; this means an approximate point or focal source of X-rays and consequent sharpness of defining power.

The apex of the X-ray stream thrown outward from the inclined reflector, as shown in Fig. 21, may be termed the focal point of the tube for all later practical purposes.

75. The impact of the kathode beam upon the reflector tends to heat the latter. It is necessary, indeed, that the reflector should get red-hot, if we require sufficient power to penetrate dense tissues and do quick photographic work. Running white-hot for very dense tissues is even better; but to endure such treatment the tube must be made with great care; even with the greatest care a tube is often a failure. This is because of the complicated character of the phenomena involved, which makes the manufacture of tubes almost entirely empirical, and a very indefinite kind of empiricism at that.

76. Wave Length.—Just as in a beam of light there may be waves of very different length, each wave-length having its own peculiar actinic power, so in a beam of X-rays there may exist many different kinds of X-rays, differing among themselves as regards their power to penetrate dense tissues.

77. Penetrating Power.—When the vacuum is high—*i.e.*, when the exhaustion is very complete—the X-rays have maximum penetrating power; when the vacuum is low—*i.e.*, when the exhaustion is very incomplete—the X-rays have minimum penetrative power. By varying the vacuum, the penetrative quality of the tube may be made as desired. Thus, with a low vacuum tube the hand casts a dense shadow on the fluorescent screen and the bones are not visible. As exhaustion goes on, the general body of the shadow becomes lighter as the rays become more penetrating, while the bones begin to stand out as darker masses. Exhausting still further, the rays

become so penetrating that the flesh shadow practically disappears while the bones become much lighter. Finally, at very high exhaustions, even the bones produce very light shadows, and often become invisible in the general flood of light.

78. In practice, a number of tubes of varying vacua should be available. For the hands and feet the vacuum should be comparatively low. The shoulder, knee joint, etc., require greater penetration, while for the pelvis, thorax, etc., the tubes require still higher exhaustions.

79. The manufacturer finds it impossible to produce a tube with a predetermined vacuum. The result is largely a matter of chance, and the tubes are generally assorted after completion, according to their actual tested capabilities.

80. Defects of Tubes.—The two defects most commonly met with in X-ray tubes are:

1. The vacuum goes down—decrease of exhaustion.
2. The vacuum goes up—increase of exhaustion.

81. Decrease of Vacuum.—This is most generally caused by running the tube too vigorously. The especial point of danger is when the reflector begins to get red. This drives out occluded vapor from its surface, and this, of course, tends to lower the vacuum. Probably the intense heat also drives off condensed vapor from the inner surface of the tube. This break-down of the vacuum is shown by the decreased penetrative power of the rays, as also by the glow in the tube changing to pink and red. It will also be indicated by a very sudden increase of redness on the reflector, due to the suddenly increased current which the lowered vacuum resistance allows to flow through the tube.

In using a new tube for the first time, therefore, treat it very cautiously and start with a very small amount of energy, gradually increasing the spark-length, until the

platinum just begins to glow; then proceed still more carefully, allowing the platinum to become red very slowly and watching closely for any signs of break-down. If the break-down does take place, stop the tube, let it cool, and begin over again. Occasionally a tube, by such repeated trials, may be gotten into a condition where the critical point may regularly be passed without trouble. Generally, however, such tubes may only be run at spark-lengths shorter than the critical one.

82. Increase of Vacuum.—All tubes which do not go down almost immediately, go up in vacuum sooner or later. The cause is not clearly understood. On the Tesla theory it is due to the fact that the kathodic bombardment is of such high velocity as to hurl air molecules right through the tube wall. Another theory does not go so far as this, but claims that the molecules are condensed (occluded) upon the inner wall of the tube.

This going up of the vacuum is indicated by increased penetration of the rays, and much more plainly by the increase of spark-length necessary to operate it. Referring to Fig. 3, it is seen that the tube is always in parallel with the spark-gap, the latter being set so as not to make an easier path across its terminals than the tube. If, then, the vacuum in the tube rises, the resistance of the latter becomes greater and the discharge leaves the tube and goes over the gap. The gap must then be lengthened to get the discharge again through the tube.

Often the tube behaves thus upon its first use. In such a case there is generally nothing to be done, and the tube must be returned to the maker.

In any case all tubes will go up in vacuum eventually—their life is thus limited. Probably the equivalent of 60 hours' continuous running is the most that could be expected, under the most favorable circumstances, from any tube.

83. A tube may go up in vacuum so high that sparks will pass around the outside of the tube between the two electrodes

rather than go through it. This generally takes place before a point is reached where the penetration is too high. If the tube is pushed as far or farther than this point, there is great risk of the spark breaking through the glass walls of the tube, which is called **piercing.** The tube so injured is said to be *pierced* or *punctured.*

84. A tube which is slowly "going up" from day to day may have its life prolonged by heating it gently and gradually but thoroughly over its whole surface with a Bunsen flame or alcohol lamp. Should this be *over* done, the vacuum may even be brought down *too low;* letting the tube *cool off* will bring it back in such a case.

Always stop the current before heating the tube, as the flame, being a good conductor, will carry a shock to the hand and probably cause accident by spilling of alcohol or breaking of tube.

85. A tube which is too high in vacuum may, of course, be opened up and re-exhausted. Most makers advertise to do so at a small charge. It is peculiar, however, that a re-exhausted tube never has the life that it had originally; 15% or 20% of the original life, at best, is all that may be expected. It is doubtful, therefore, if it pays to re-exhaust tubes.

86. Punctured tubes may often be repaired and re-exhausted, though as to re-exhaustion the remarks just made also apply. Many punctures cannot be repaired, as the glass often resists reheating and simply flies into fragments when such an attempt is made.

87. Tubes are often seen to have long air-streaks in their walls. These streaks light up vigorously during discharge, owing to electrostatic action, which will eventually puncture the glass unless care be exercised. If not in the direct path of the X-rays, such spots may be greatly strengthened by covering them with hot paraffin; this is equivalent to increasing the thickness of the glass at this point.

88. Control of Vacuum.—Fig. 22 illustrates a typical form of tube designed to place the vacuum under control. It differs from the tube of Fig. 21 only in that there is a small side tube near one end, in which is sealed either a little caustic potash (KOH) or phosphorus pentoxide (P_2O_5). Either of these chemicals has great affinity for water, so that by driving off most but not all of the water during exhaustion we may, at any time, fill the tube more or less with water vapor by merely applying heat to the little bulb. A similar method, used to some extent in

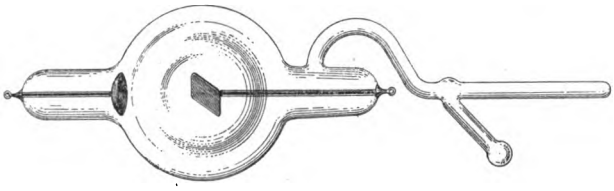

FIG. 22.—TUBE WITH ADJUSTABLE VACUUM.

England, employs a piece of palladium in the "by-tube." The tube is filled with hydrogen before exhaustion. The palladium absorbs or occludes from 900 to 1,000 times its bulk of hydrogen at ordinary temperatures, and this is given off again by heating.

89. The difficulty with all such "potash" tubes, as tubes of this class are generally called for lack of a better name, is that of applying just enough heat and not too much or too little. The expedient, again, is but a temporary one, and eventually the vacuum will go up despite the device, as the potash and phosphorus pentoxide finally lose the power to take up and give out water vapor. As to the palladium tube, information is lacking.

90. Fig. 23 illustrates another form of focus tube. It is small, only about $4\frac{1}{2}''$ long by $\frac{3}{4}''$ to $\frac{7}{8}''$ in diameter. The bulb is blown out exceedingly thin on one side of the tube only. On the inner surface of this bulb is placed a sprinkling of the mineral earth "Smithsonite"—sometimes calcium

tungstate. The radiated heat from the platinum reflector seems to drive out a small amount of vapor from the mineral, and thus tends to prolong the life of the tube.

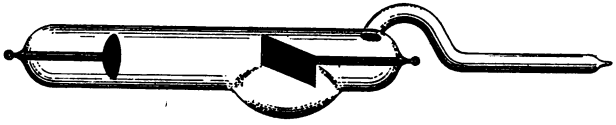

FIG. 23.—SMALL FOCUS TUBE.

A tube recently brought out is shown in Fig. 24. It resembles the former tube, except that the material to be heated —probably caustic potash—is not placed in the main bulb, but at the extremity of a small "by-tube" opposite a small kathode disc, the stream from which continually bombards and heats the chemical sufficiently to throw off the necessary amount of vapor.

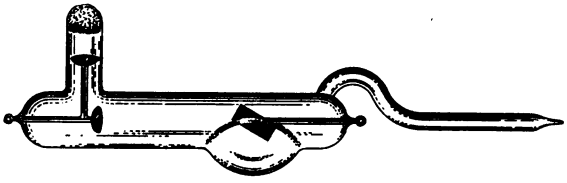

FIG. 24.—ADJUSTABLE VACUUM TUBE.

91. Adjustable Vacuum Tube.—A tube in which the vacuum may be set to any desirable value and continuously held there is ideal. Fig. 25 illustrates such a tube, one of the best of the many attempts which have been made in this direction. T is the tube proper, which is perfectly orthodox in design. Near one end is sealed on a "by-tube," Z, containing potash, while around this "by-tube" is sealed an auxiliary tube, G, which is exhausted to a low vacuum. E, the kathode of tube G, is set to bombard A, while without, it terminates in an arm, K, which pivots upon P so as to increase or decrease the spark-gap D. With C and A connected to the generating source, the discharge may pass from C to A through the large tube,

producing X-rays, or it may pass around across D and through the small tube G. Whatever path the current follows depends upon the relative resistances of the circuits.

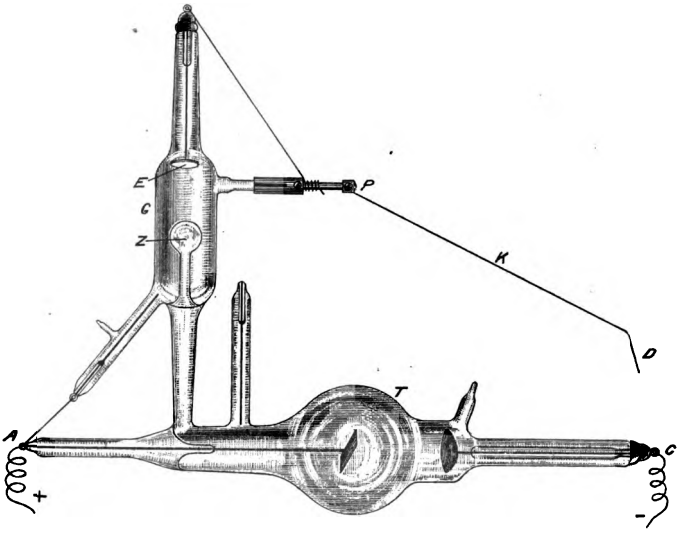

FIG. 25.—ADJUSTABLE VACUUM TUBE.

If, now, D is made very short, a large proportion of the discharge goes by way of P, bombarding as it goes. This lowers the vacuum in tube T, until at last its resistance becomes so low that the discharge prefers T to G. The vacuum now tends to maintain itself at this point, no matter how long the tube is run, the discharge balancing back and forth from one tube to the other accordingly as the large tube becomes higher or lower in resistance. To obtain any desired higher degree of vacuum the gap D is made greater; a larger E. M. F. may now be given to the tube before the lowering action of G sets in, so that the vacuum remains permanently higher.

This tube gives very satisfactory results and allows of the use of a very large amount of energy. The design is of necessity clumsy, and the tube hence liable to breakage in transit or use. It suffers from the common disadvan-

tage of all potash tubes, viz., the essential failure of the potash to release and absorb the vapor.

92. Fig. 26 shows the form of tube used with the Tesla coil. It is commonly known as the **"double focus tube."** There are two exactly similar kathodes, one at each end of the tube, while in the middle is a wedge-shaped reflector, R. The two terminals of the Tesla coil are joined, one to each of the two kathodes. Since the Tesla discharge is an alternating one of extremely high frequency, each of the two kathodes is thus similarly in action, each focusing its rays upon its half of the wedge reflector, R. X-rays proceed, therefore, from each side of the wedge.

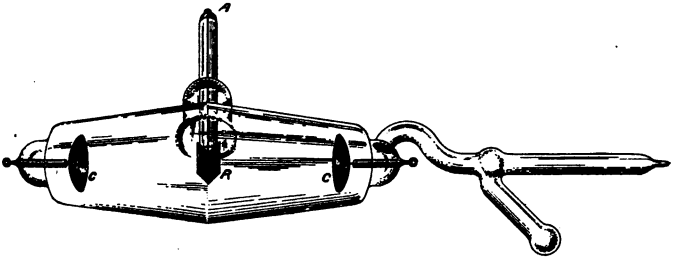

FIG. 26.—DOUBLE-FOCUS TUBE.

The definition of images with the double-focus tube and Tesla coil is never so good as when an induction coil and single-focus tube is used, since the two focus points, though near, are still a very appreciable distance apart and each casts its own shadow. The life of the double-focus tube, as of any tube used with the Tesla coil, seems much more limited than that of tubes used with direct current apparatus.

The double-focus tube may be used on an induction coil or a static machine by joining the two kathodes, C, together, and the negative of the apparatus to the reflector, R, which becomes the positive or anode, A. There is, of course, produced the same defective definition as with the Tesla coil.

93. Stands.—A stand for an X-ray tube should have a heavy base, so as to avoid risk of upsetting. Its parts should be so arranged with suitable joints that the tube can be placed in almost every possible position with reference to a patient. The jaws which clamp the tube should have a considerable range of opening, so as to accommodate tubes of different sizes. These jaws must not have metal parts near the tube, as such set up condenser effects relative to the tube, and sparks are liable to pass and puncture

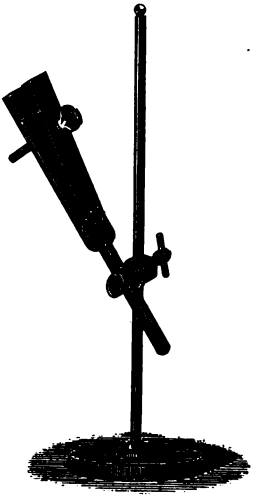

FIG. 27.—STAND.

the tube. The clamps should be faced with cork or leather to prevent possible breakage due to clamping pressure.

94. Figs. 27 and 28 show two well-known forms of stands; the small stand is of wood and cheap. For all practical purposes of the surgeon it is worthless, being merely intended for show work with the hand, coins, etc.

The stand in Fig. 28 is made of bicycle tubing and has a heavy metal base. With it the tube may be placed in any position within a cylinder 6 feet high and 6 feet in

diameter. The clamps are long and of wood, while the wires are held at the extremities of vulcanite supporting rods by little spring clips. An advantage of these clips is that in case of sudden strain on the connecting wires

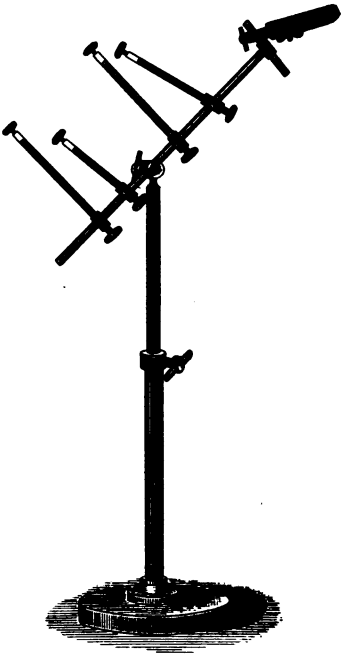

FIG. 28.—STAND.

they merely slip from position, instead of breaking or transmitting breaking strain to parts of the apparatus.

FLUOROSCOPES AND FLUORESCENT SCREENS.

95. The fluoroscope is an instrument used for the convenient and easy examination of X-ray shadows; a conventional pattern is shown in Fig. 29. It is merely a flat screen of cardboard or thin wood, having upon one side a uniform coating of a fluorescent salt or chemical. This salt must

be in crystals of a certain definite and rather small size, and is put on the screen according to certain methods which remain largely a trade secret of the manufacturer. Around the edge and on the coated side is fastened a hood, flaring from the screen to the eyes, where it terminates in a soft flapped opening fitting closely to the eyes.

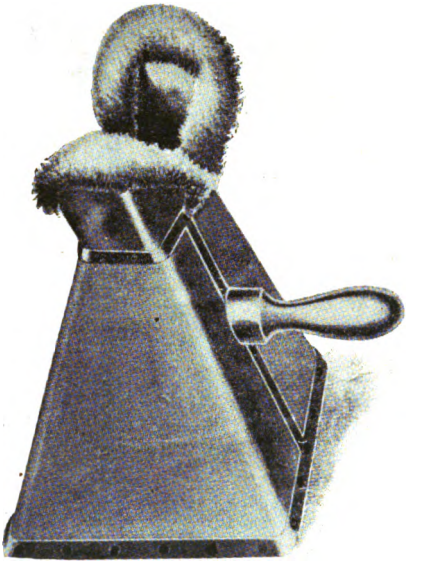

FIG. 29.—FLUOROSCOPE.

96. Fig. 30 shows the fluoroscope in use, it being held much as would be an ordinary stethoscope. The object to be examined is placed close against the fluoroscope and between it and the tube. The hood, of course, merely serves to shut off superfluous light and thus preserve the sensibility of the eye.

97. The salts principally used for fluorescent screens are tungstate of calcium and platino-cyanide of barium. Screens made with the calcium salt are a little cheaper than those made with the platinum salt, but do not give

as clear and sharp images. This objection is due to the strongly phosphorescent quality of the calcium salt, and increases with age. It is indicated by a persistence of the old image after each change of position of the fluoroscope in use, as well as by a general illumination of the whole surface; the old and new images thus blur into one another. This effect is so bad, indeed, that after six or eight

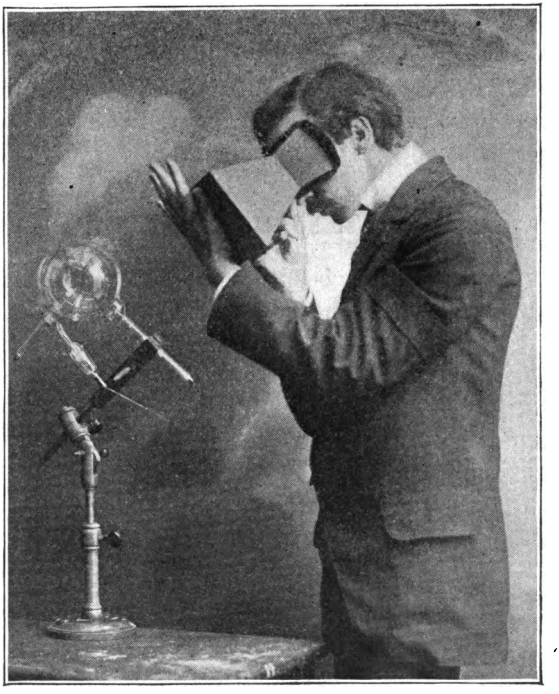

FIG. 30.—FLUOROSCOPE IN USE.

months' use a tungstate screen will retain a visible image for several minutes after the tube has stopped, so that the screen is practically worthless.

The platino-barium-cyanide screen has a distinctly green tint when fluoresced, and gives a sharp, brilliant picture. It has no appreciable phosphorescent quality.

98. For exhibitive purposes, or even general diagnostic work, a **fluorescent screen,** as distinguished from a fluoroscope proper, is often used. The screen is essentially the fluoroscope without the hood. It may be made of any desired size suited to the purse of the purchaser (fluorescent screens are generally sold by the square inch) and may be simply framed. The screen surface proper should be covered with a plate of thin glass or transparent celluloid to prevent accidental abrasion or soiling.

In using the fluorescent screen the room must be kept very dark, since the hood for protecting the eyes from extraneous light is not present.

RADIOGRAPHY.

99. As has already been pointed out, the image produced upon a photographic plate by X-rays is not a photograph but a shadowgraph. To speak of *X-ray photography* is, therefore, not strictly correct. Several words have been coined to denote this species of image, such as radiograph, skiagraph, shadowgraph, etc. The term *radiograph* seems to have been more generally accepted.

100. In making an X-ray picture, a sensitive dry plate of almost any of the reliable makers will give good results, and long experience makes it impossible to pronounce any special brand as of marked superiority. In general the emulsion should be rather thick, the thinly coated plates not being so rich in detail.

101. Special X-ray plates are now made and used by many operators. Some of these are known to contain a fluorescent salt as one of the ingredients of the emulsion. Others probably possess no distinctive feature beyond the label. Those obtained from reliable sources, however, are said to give better detail of shadows than the ordinary plate.

102. In making an X-ray picture, the object must be placed as close to the film side of the plate as possible. The plate may be in the usual plate holder, or preferably in a light-proof envelope. Some makers supply plates already packed in such envelopes, making them thus available for immediate use.

103. Rules of Exposure.—The plane of the plate should be perpendicular to the axis of greatest intensity of the tube and with its center intersected by this axis. The object to be radiographed should lie flat upon the film side of the plate, between it and the tube.

104. The distance of the tube from the plate is regulated principally by the thickness of the object to be radiographed or exposed. If the object is thin, the tube may be brought quite close; but if the object is dense, the tube must be at a greater distance if we are to avoid distortion of the shadows.

The time of exposure seems to be practically the same for any of the reasonably sensitive plates when used under the same conditions.

105. In speaking of the tube with reference to its distance from the plate, we have in mind the platinum reflecting mirror of the tube, since this is the center of radiation of X-rays.

106. X-rays go out in all directions from the platinum disc in straight lines. The law of illumination or of effectiveness of X-rays is, therefore, the same as that for light—viz., the energy falling upon any surface perpendicular to the axis of the rays, varies inversely as the square of the distance between the surface and the radiant source; hence there follows:

107. Law of Exposure.—Other things being equal, time of exposure varies directly as the square of the distance between tube and plate. This law may be algebra-

ically expressed as $\frac{T_1}{T_2} = \frac{D_2^2}{D_1^2}$, where D_1 and D_2 are the two distances corresponding to the two times T_1 and T_2.

Example.—Required the time for a good shadowgraph at 20″, if 2 minutes suffice for a good result at 10″.

Solution. $\frac{T_1}{2} = \frac{\overline{20}^2}{\overline{10}^2}$ $\therefore T_2 = 8$ minutes. Ans.

108. There is a **second law of exposure**—viz., that the time of exposure varies directly as the thickness or density of the object; this is only an approximate law, however.

109. The radiograph is even more affected for good or bad by the detailed method of development and treatment than is the ordinary photographic negative. Everything depends upon the individual skill of the operator during development. For this reason different persons will often require very different times to produce the same result in X-ray work, even when using identical apparatus.

THE TREATMENT OF THE EXPOSED PLATE.

110. Inasmuch as the methods employed for exposing the plate to obtain an X-ray picture, or radiograph, will be described later in *Practical Radiography*, all that remains to be considered are the practical photographic means used in the preparation of the exposed plate and its special adjuncts.

The exposed dry plate is taken to the "dark-room"—a room from which all white light is excluded—and taken from its light-proof holder. A ruby lamp is necessary to light the dark-room for such purposes.

The bare plate is then ready for **developing.** Developing means to bring about a chemical change in the film of the plate, so as to separate shadows from lighter areas,

brought about, in this case, by the action of the X-rays upon the object interposed between the film and the tube.

Solutions for developing are called **developers.**

Restrainers are chemicals used to restrain or retard the action of developers. The one most used is *potassium bromide.* The addition of water to the developer weakens its action. An excellent developer, that can be used for almost any dry plate made, is prepared as follows:

Solution No. I.

Distilled Water	30 ounces.
Sodium Sulphite (crystals)	3½ "
Oxalic Acid	1 drachm.
Eikonogen	1½ ounces.
Prussiate of Potash (yellow)	1 ounce.

Dissolve the eikonogen in hot water and add the chemicals and rest of the water to it. Mix thoroughly and set aside to cool, marking the Solution, No. I.

Solution No II.

Distilled Water	20 ounces.
Carbonate of Potash	2 "

Mix and dissolve, labeling this, No. II. To make the developer, take four ounces of No. I. and one-half ounce of No. II. Mix and it will be ready for use.

The above solutions should be kept in a cool, dark place. In summer it is advisable to allow the developer to get cold, by setting it upon ice for a time, before using. In winter it should have a temperature of about 70° F.

The developer is put into a hard-rubber or porcelain tray and the exposed plate laid into it—film side up. (This side has a duller appearance than the plain glass. All bubbles should be carefully brushed off with a camel's hair brush.) Almost immediately a change in the appearance of the film will be noticed. The unaffected parts will remain light, while the more exposed areas will get almost black.

The time of development varies with the time of exposure

and the object exposed. The operator will soon learn to know when to stop developing, by comparing the value of detail and shadows. A good way to determine a fair development is to note the image from the glass side of the plate. When this shows fairly clear, the development may be stopped.

111. Fixing.—The plate after development becomes the **negative** and will hereafter be so termed. It is now removed from the developer, washed for a few moments in running water and **fixed** by placing it into the *fixing bath,* made as follows:

Fixing Bath.

Water..... .....1 gallon.
Hyposulphite of Soda.....2 pounds.

After the soda has dissolved, the solution is ready for continual use, until too weak, when a fresh one may be prepared.

The negative is placed into the above and allowed to remain therein until the back of the film becomes clear, unmottled and perfectly transparent. It may then be brought out into the light and inspected. The fixed negative should be washed at least 20 minutes in running water to remove all traces of "hypo," which has a tendency to spot the prints made from it and may even destroy the entire image in time.

Films may be used instead of dry plates, but they are difficult to handle, requiring much care in the hands of an amateur. Their advantage is their light weight and practical unbreakability.

Bromide paper may also be used in place of the dry plate, remembering, however, that in that event no prints can be made from the image thus obtained.

112. Should the negative be indistinct or too thin it may be greatly improved by **intensifying** it. This can be done as follows:

Wash the plate thoroughly until the film has become soft, and place it into the following solution:

Intensifying Solution.

Water	50 parts.
Bichloride of Mercury	1 part.
Bromide of Potassium	1 "

It will be noticed that the film becomes milky-white—in other words, is bleached. It is then removed from the solution and placed into a second, composed of equal parts of a saturated solution of sulphite of soda and water, or another solution made of concentrated ammonia 1 drachm and water 1 pint.

The negative will again become black gradually, and is allowed to remain until the density desired is obtained. It is then washed very thoroughly and allowed to dry as any ordinary negative. Negatives should be dried in rooms free from dust and having a temperature of about 70° F. Never place the wet negative into sunlight or near a stove to dry; it melts the film and destroys the entire plate.

113. Printing.—Prints are sensitized paper reproductions of the negative image, containing its reversed likeness or positive.

A number of printing papers can be obtained in the market; the collodion or albumen papers are to be preferred.

To make a print, the negative, film side up, is laid into a frame made for the purpose; the paper with its film side laid in contact with the film of the negative, and then exposed, to sunlight until the sensitized paper becomes of a dark reddish-purple hue. It is then removed and ready to be **toned.**

Any number of prints may be made from one negative.

The print obtained should be placed into a light-proof box or room until toned.

114. Toning.—A great many amateur operators use the so-called *combined bath;* it proves unsatisfactory in every

way, because pictures made with it fade quickly. The proper solution to use is a *separate bath*, made as follows:

Solution No. I.

Water.....20 ounces.
Sodium Acetate ..... 5 grains.
Borax (powdered) ..... 5 "

Solution No. II.

Chloride of Gold (Merck).....15 grains.
Water..... .....16 ounces.

For toning, take 20 ounces of No. I. and ½ ounce of No. II. solution.

The prints are placed into the above "toning-bath" after being first washed 20 minutes in fresh water, and allowed to remain until the desired shade is obtained. They are then placed into clean water before fixing. It is desirable to keep the toning bath alkaline. This may be determined by the aid of strips of litmus-paper placed into the solution; by the change of its color the nature of the bath is determined.

The addition of a little saturated solution of sodium acetate keeps the bath as desired.

To fix the prints, they should be placed into a bath composed of

Sodium Hyposulphite.....1 ounce.
Water.....1 pint.

The toned prints should remain at least 20 minutes in the above.

The prints are then removed and placed into a **hardening bath** composed of

Alum.....½ ounce.
Water.....1 pint.

The latter may be added to the fixing bath to save time.

The prints are next thoroughly washed for at least an hour in running water, and mounted on card-mounts with starch-paste.

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